X-shooter Science Verification Proposal

The most luminous young super star clusters – clues to cluster formation and Lyα physics

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Abstract:

We propose to observe three of the most luminous and massive ($\sim 10^7 M_\odot$) young ($\sim$ 10 Myr) super star clusters in the local universe, found in two metal-poor starbursts. From these observations we can determine stellar and nebular abundances and kinematics, masses and feedback processes, extinction structure, stellar populations to advance our understanding of the formation and nature of such objects. In addition, the proposed observations will be vital for improving our understanding of Lyman alpha emission and radiative transport from starburst regions.

Scientific Case:

A major fraction of star formation in the most extreme local starburst galaxies takes place in massive (10^5-10^7 $M_\odot$) stellar clusters, and these have Lyman continuum photon production rates far higher than ordinary star clusters.

Such massive clusters not just preferentially observed in starburst galaxies. They are also by virtue of their brightness the smallest observable units of stellar populations at high and intermediate redshifts. Like their older counterparts the globular clusters, they are at least in principle easily modeled with simple stellar population models.

In extreme starburst environments of the kinds we see at z$\sim$1-2 and higher, galaxies were smaller, younger and were forming both by mergers and by accretion of cold gas from the cosmic web.

Lyman α is in simple recombination theory expected to be the strongest of all emission lines, and up to one third of the ionizing power may be reradiated as Lyα. Combined with a suitable wavelength for high redshift studies, it has therefore become the major tool for probing star forming galaxies in the distant universe. However, detailed studies of low redshift starbursts (Giavalisco et al. 1996, ApJ 466, 831; Kunth et al. 1998 A&A 334, 11; Mas-Hesse et al. 2003, ApJ 598, 858; Östlin et al. 2009, in press, arXiv0803.1174) have demonstrated that Lyα radiative transport is very complex: normal extinction corrections fail, and in all, the ISM kinematics appears as important as the dust content for the ability of Lyα to escape a galaxy. Given, the potential of Lyα for high-z studies, an improved physical understanding of the radiative transport in vital and part of the goals for the current proposal.

We want to study the most extreme young massive clusters in two extreme galaxies: Haro 11 (ESO 350–38) and ESO 338–04 (Tol 1924-416), rare examples of blue compact galaxies in the local universe that are both luminous ($M_B < -19$) and metal-poor ($Z \sim 0.1 Z_\odot$) (Bergvall & Östlin, 2002, A&A 390, 891). The clusters have presumably been formed under conditions similar to those seen at high and intermediate redshifts in for example Lyman break galaxies (Overzier et al. 2008, ApJ, 677, 37). These are also rare examples of star clusters for which Lyα imaging data exists (Hayes 2005, A&A 438, 71; 2007, MNRAS 382, 1465; Östlin et al. 2009, in press, arXiv0803.1174). Both also belong to the rare class of objects for which there is tentative evidence from the FUSE satellite for partial Lyman continuum escape (Bergvall et al. 2006, A&A 448, 513; Leitet et al in prep).

All clusters have previously been studied by us, but with X-shooter the unique opportunity to get a consistent spectrum from the atmospheric cutoff to the thermal IR has arisen. The clusters are sufficiently bright that we can get excellent S/N on all three in no more than 4000s including overheads. These observations will shed light on a number of open issues:

The knots in Haro 11 have previously been studied by FORS2 and FLAMES spectra of the visible and the region around the Calcium triplet (CaT). It is clear that both B and C are massive objects ($> 10^7 M_\odot$, although the available spectra were not optimized to study the clusters). This is concluded also from our HST photometry and SED fitting (Adamo et al. 2009, in prep.). Knot C has an age of 2×10^7 yr as indicated by the Balmer absorption, whereas the SED fitting and specifically the strong Lyα emission implies a much lower age. The presence of strong CaT absorption (EW> 10Å) proves the presence of evolved red super giants and suggest a high metallicity. This demonstrate that this cluster is not a simple stellar population. Despite the strong Lyα, knot C has the highest extinction of the knots in Haro 11, and dust aligned with the ellipticity of the cluster can be hinted in HST images. The Lyα emission is extended perpendicular to this direction and may be caused by an outflow or resonant scattering. An X-Shooter spectrum aligned with this Lyα feature would allow us to trace the ionized gas kinematics and would also be important for the preparation of a future HST/STIS proposal.

Knot B is younger as inferred by the Hα equivalent width, but here Lyα is seen in absorption. Even if no Lyα comes out, the intrinsic production rate must be much higher than in C, and we will investigate the possibility of detecting H2 fluorescence pumped by Lyα (Shull 1978, ApJ 224, 841). No CaT absorption has been detected, but this would easily drown in strong Paschen emission present. With X-Shooter we will investigate the presence of CO bands from which we can constrain the number of red super giants (to measure the age) and derive the dynamical mass.

Cluster #23 in ESO 338–04 has a confirmed dynamical mass in excess of $10^7 M_\odot$ making it the most massive confirmed *young* cluster known (Östlin et al. 2007). SED fitting and Balmer absorption indicates an age of around 6 Myr. It is bright in Lyα but surprisingly faint in Hα, with Lyα/Hα reaching values well *above* the recombination value – a smoking gun for non-standard radiative transport of Lyα photons.

The wide wavelength coverage of X-shooter allows us to simultaneously measure emission line fluxes over the whole spectrum. This means we can get accurate values of the extinction (and probe the distribution of optical depths through use of many Hydrogen lines at various wavelength) and density and temperature-sensitive line ratios, plus reliable fluxes in a number of metallicity-sensitive lines. For instance, with X-shooter we can measure the OI doublet at 1.13 μm, which would be a signature of a dense optically-thick gas, which means the OI is presumably tracing the same gas that produces the Ly series. We would also study [Fe]1.6μm which traces SNRs. In addition, the good continuum S/N will allow us to measure all absorption line indices (e.g. in the Lick system) which will be used to further constrain the stellar population age/star formation history and metallicity. In addition, some absorption lines like NaI D give us information on the column and velocity of neutral gas along the sight line which is crucial for understanding the Lyα radiative transport.

In summary, the proposed observations would allow us to make a study of unprecedented accuracy of the most luminous young star clusters in the local universe and determine their nebular abundances, densities, kinematics as well as the stellar populations and its dynamical and stellar mass.

Targets and observing mode

Target	RA	DEC	B mag	Mode (slit/IFU)	Remarks
Haro 11 knot C	00 36 52.5	-33 33 19	17.6	slit	First priority
Haro 11 knot B	00 36 52.5	-33 33 19	18.6	slit	Third priority
ESO 338-IG04 cluster #23	19 27 58.2	-41 34 32	17.3	slit	Second priority

Time Justification:

The objects proposed here are all bright and hence make up excellent SV targets. The faintest object is knot B in Haro11 with $U = 17.7, B = 18.6, I = 17.7, H = 15.6$. Knot C has the same H-band flux but is one mag brighter at B. We will use at 0.8 arcsec slit in UVB, 0.9 in VIS and NIR to reach a resolution of $R \approx 6000$ or above, which will allow us to measure the velocity dispersions and any rotation with sufficient accuracy (the instrument resolution corresponds to $\sigma = 14$ to 23km/s). Cluster `inner`#23 in ESO 338–04 has the same visual brightness as Haro 11–C although no IR magnitude is available. Hence, Haro 11–B will be our "worst" case. Still, with a moderate exposure time of 2×400s we can reach a very decent signal to noise according to the ETC: for any wavelength greater than 3500Å, we will get a continuum S/N per spectral bin of above 10 (and greater than 20 above 4000 Å)in the continuum. Of course, the S/N of emission lines will be considerably higher. The S/N in the VIS and NIR arms will be higher or comparable.

In total. In 4000s, just slightly above one hour in total, including overhead, we can observe the three clusters.